TIE-GCM and WACCM-X:
Atmosphere-Ionosphere Model Development at NCAR

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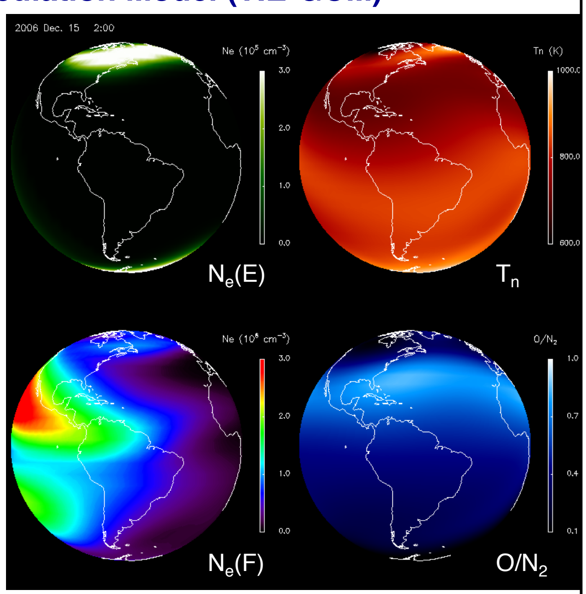
Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

- Original development by Ray Roble, Bob Dickinson, Art Richmond, et al.
- The atmosphere/ionosphere element of the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) and LFM-TIE-RCM (LTR) models
- Cross-platform community model, under open-source academic research license
- v. 2.0 release, 2016
- User guide complete
- Documentation mostly complete
- Runs-on-request at CCMC



- More information at: http://www.hao.ucar.edu/modeling/tgcm

What's New in TIE-GCM v. 2.0?

- TIE-GCM v. 2.0 released in March 2016
  - "Double Resolution" (2.5° x 2.5° x H/4) supported
  - Helium included as a major species
  - Electrodynamics calculations parallelized

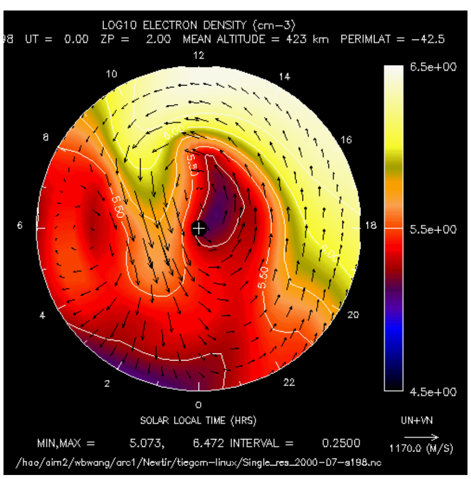
- Recommend 30-second time step for double res., 60-second time step for single-res.

- Other new features:
  - Argon as a minor species
  - IGRF12 and secular variation
  - Non-migrating GSWM tides turned on in default inputs for high-res only
  - Lower boundary zonal mean climatology
  - CTMT (Oberheide/Forbes) tidal option
  - AMIE interface merged to trunk
  - CMIT interface updated
  - ZG and (optionally) ZGmid output to secondaries
  - N_2 now its own field, optionally output to secondaries
  - Many other optional secondary diagnostics (not all of these are new):
    - Mass density, He, O/N_2, Scale Height, μ_{bar}
    - N_mF_2, H_mF_2, TEC, vi_{EXB}, σ_H, σ_P, λ_H, λ_P, **B**, **E**, Φ
    - CO_2 and NO cooling rates, EUV heating Joule heating
    - Aurora, cusp, and drizzle parameters

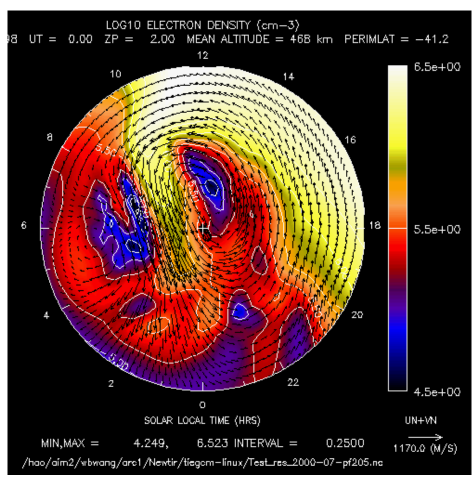
3

Normal (5°) vs. Double (2.5°) Resolution: Auroral Dynamics

Normal Resolution



Double Resolution



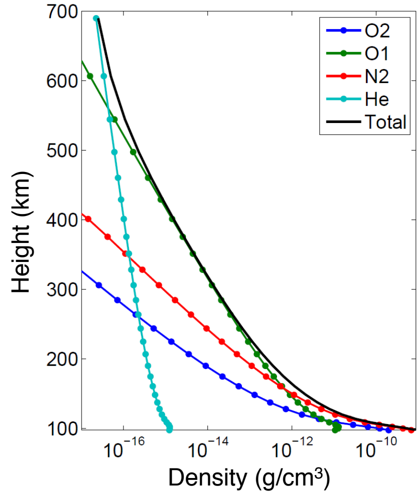
Electron densities with neutral wind vectors superimposed over the southern hemisphere polar region during a geomagnetic storm. The "tongue" of ionization is significantly more resolved in the double-resolution version of the model.

4

Inclusion of Helium as a Major Species

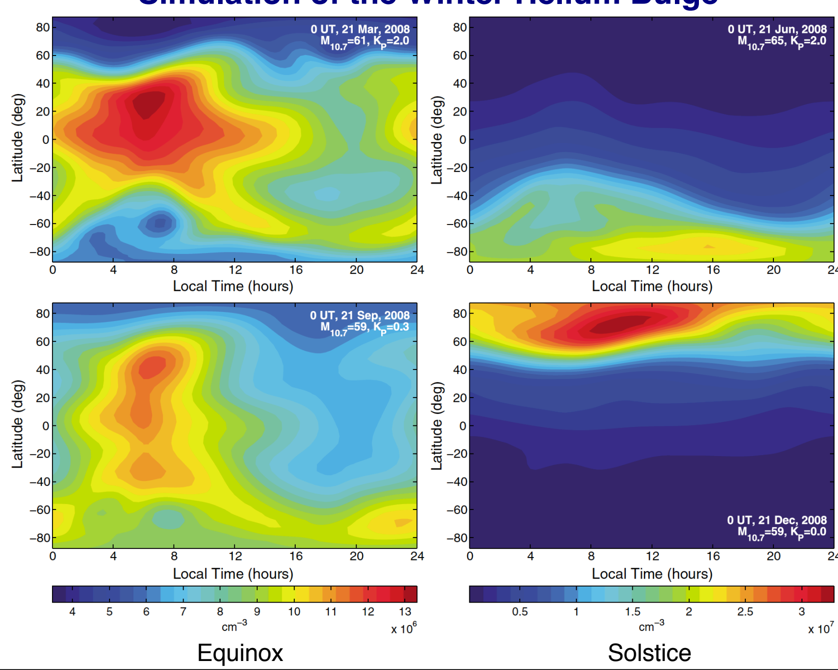
- Helium has very small concentration from ground level through the turbopause
- Diffusive separation causes the mixing ratio to increase, approaching unity near the exobase
- Seasonal variation termed “Winter Helium Bulge”
- Local Time preference near ~8:00 LT
- Helium scale height is less sensitive to solar cycle variations (i.e. temperature changes) than are other species
- Helium can be important for satellite drag calculations, particularly at 500–700 km, and partiuclarly during solar minimum

Mass Densities (Dec. 2004, 72.5° N)

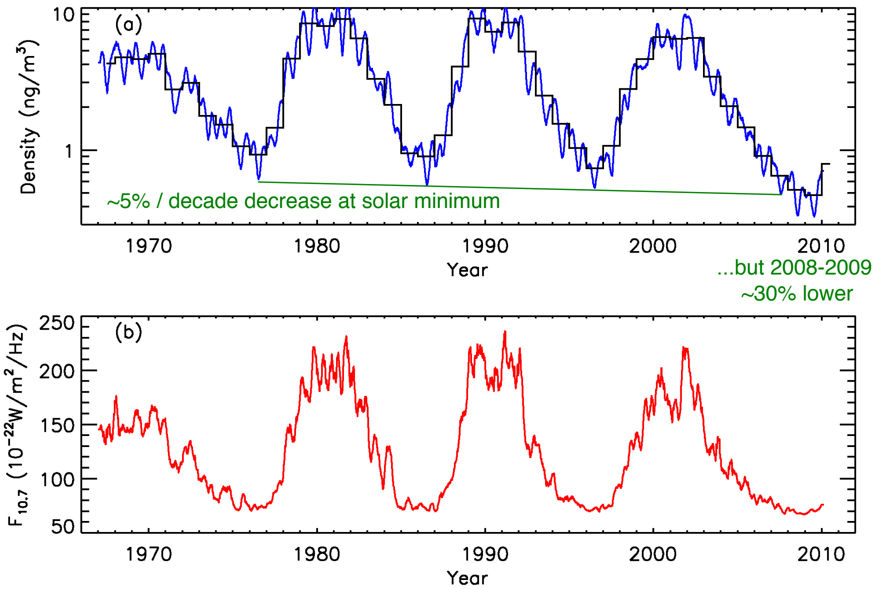


Sutton et al., J. Geophys. Res., 2015

Simulation of the Winter Helium Bulge



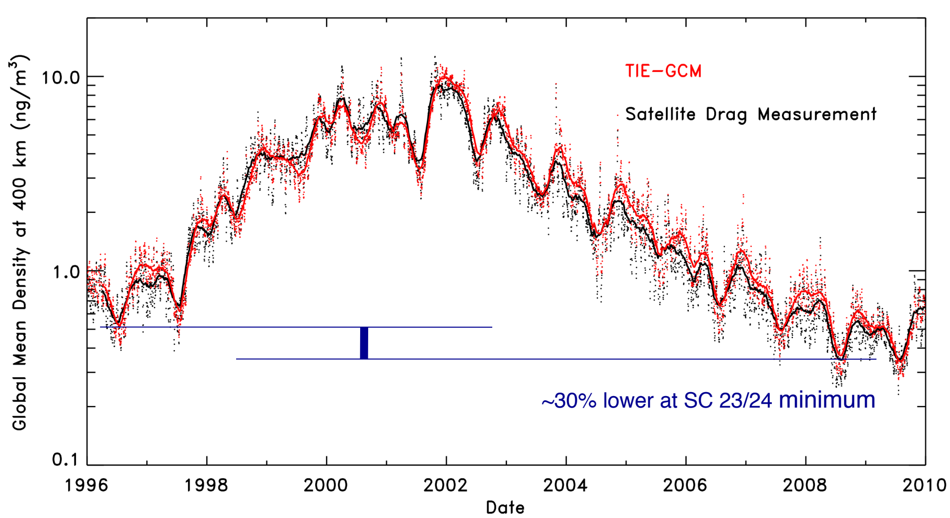
Solar and Anthropogenic Effects on Thermosphere Climate



Top: Global average neutral density at 400 km, 81-day average and annual average

7

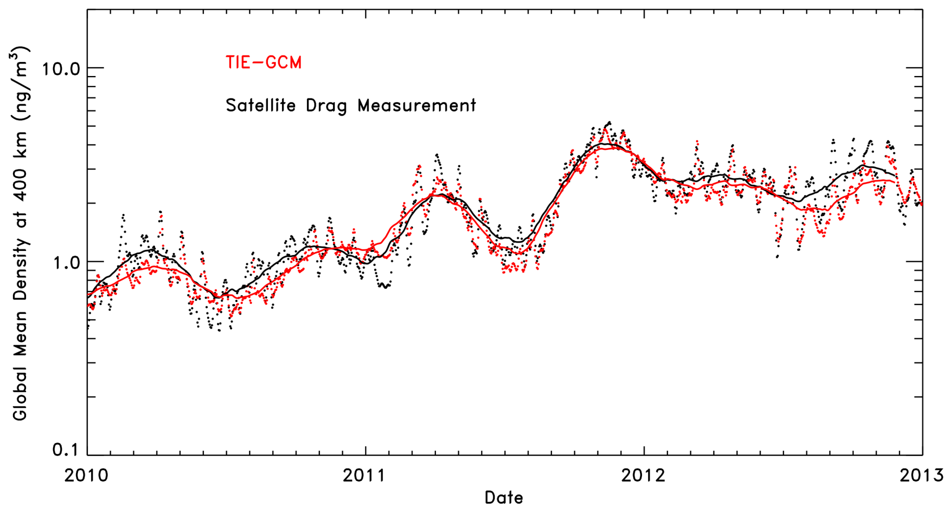
Thermospheric Density During Solar Cycle #23



Simulation of neutral density at 400 km by the NCAR TIE-GCM v. 1.94
Mg II c/w ratio used as proxy solar input, yields ~10% EUV decrease 1996-2008

8

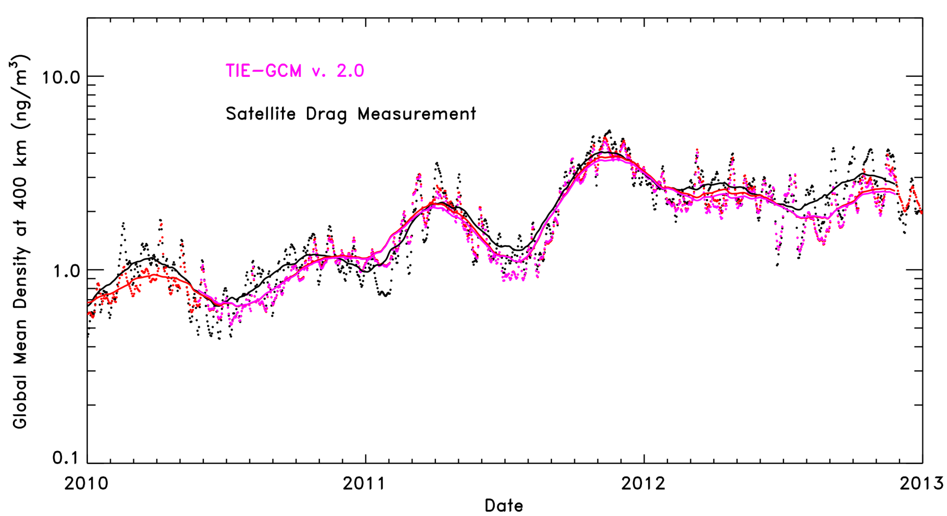
Thermospheric Density During Ascent of Solar Cycle #24



Simulation of neutral density at 400 km by the NCAR TIE-GCM v. 1.94
Using F10.7 since it is in good agreement with Mg II c/w ratio during these years

9

Thermospheric Density During Ascent of Solar Cycle #24



Simulation of neutral density at 400 km by the NCAR TIE-GCM v. 2.0
Using F10.7 since it is in good agreement with Mg II c/w ratio during these years

10

Global Mean Density modeled by TIE-GCM v. 2.0

- New version didn't disrupt reasonably good agreement with global mean satellite drag observations that was previously obtained.

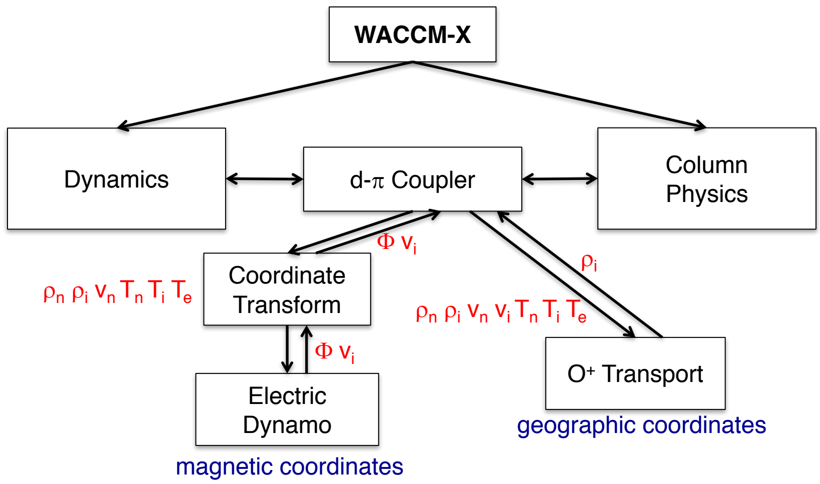
- Addition of helium as a major species did not significantly change results at 400 km *for the global mean*.

- Winter/summer and day/night density gradients are significantly impacted, however, especially at higher altitude. Further investigation is required.

Whole Atmosphere Community Climate Model – eXtended (WACCM-X)

- WACCM-X is the thermosphere-ionosphere extension of WACCM
- WACCM is the upper atmosphere version of the Community Atmosphere Model (CAM)
- CAM is the atmosphere component of the Community Earth System Model (CESM)
- Recent developments:
  - Ion and electron energetics implemented:
    - Calculating T_i and T_e in WACCM column physics.
  - Equatorial electrodynamo installed:
    - ESMF interpolation from geographic to geomagnetic coords.
  - Ionospheric dynamics installed:
    - Ambipolar diffusion and 3D transport of O^+.

Integrating Ionospheric Dynamics into WACCM-X



d-π Coupler: dynamics-physics-ionosphere-electrodynamics (D-PIE) coupler
Electric Dynamo: calculates global electric potential resulting from wind-driven ions
ρ: density v: velocity T: temperature n: neutral i: ion e: electron Φ: electric potential

13

WACCM-X Global Change Simulation Methodology

- Solar minimum conditions:
  $F_{10.7} = 70$, $K_p = 0.3$

- Two sets of runs one-year runs to simulate change in a 30-year interval:
  one with CO_2, CH_4, and CFCs from 1971
  one with CO_2, CH_4, and CFCs from 2000

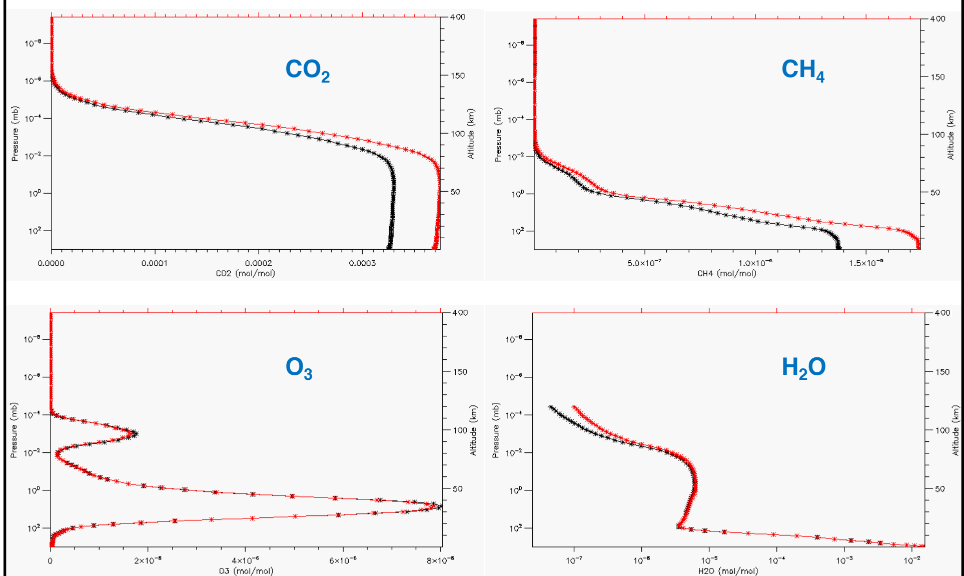
- Full WACCM-X free-running climate simulations
  but using specified SSTs — no interactive ocean or sea ice, etc.

- Three-month burn-in period to allow thermosphere to equilibrate

- Decadal change rates estimated by scaling from 30-year interval to 10 years

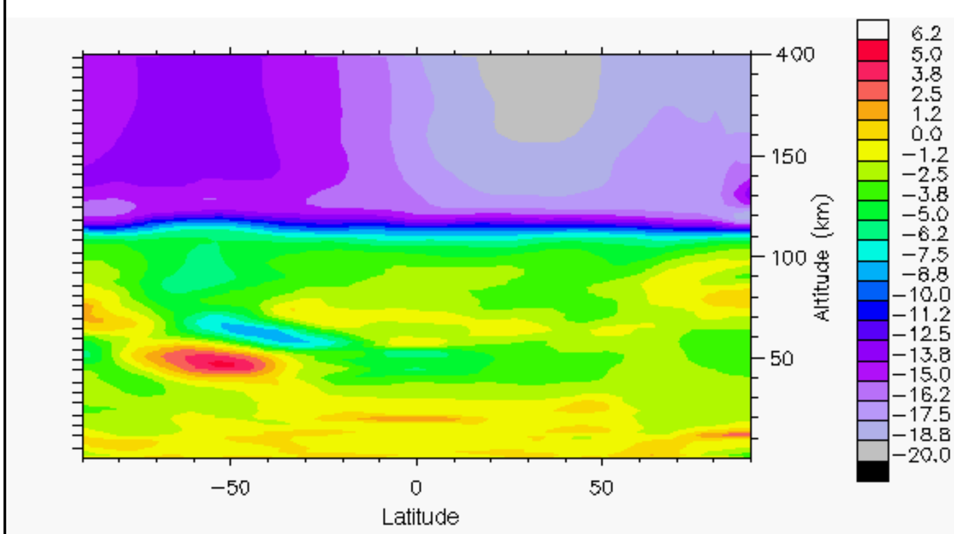
14

Anthropogenic Global Change, 1971 to 2000



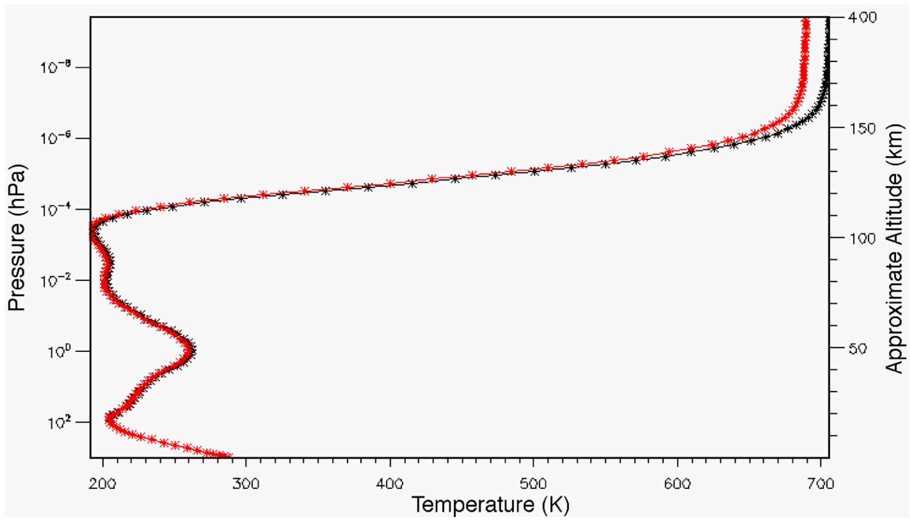
15

Zonal Mean Temperature Change, 1971 to 2000
Solar Minimum, June Monthly Average



16

Global Annual Mean Temperature Change, 1971 to 2000 Solar Minimum Conditions



17

Current Development and Future Plans

- TIE-GCM v. 2.0 released March 2018.
  - — Still some “known issues”
  - — See the release notes for more information
  - — User Guide sgnificantly enhanced
- WACCM-X development ongoing.
  - — Targeting ionosphere module for inclusion in CESM v. 2 release next summer
  - — Ionosphere is up and running, climate simulations are ongoing
  - — Next step is to include a fully-coupled ionosphere-plasmasphere module
- Other key research developments include:
  - — Lower atmosphere forcing:
    - - Seasonal/spatial variation of lower boundary eddy diffusion
    - - Tidal forcing options and data assimilation
  - — External forcing:
    - - Solar EUV updates
    - - Magnetospheric inputs (AMIE, AMPERE, LFM, other)
  - — Modeling support for upcoming NASA missions, including ICON and GOLD.

18